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A REVIEW OF HOISTING AND HAULING ALTERNATIVES IN THE MINING INDUSTRY

Report No 91-261-K

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ABSTRACT

There are a number of alternatives for hoisting and hauling in mines which will have an impact on the electricity consumption. Two opportunities that have a total load reduction potential of approximately 6 MW involve the replacement of motor-generator sets with static converters, and the utilization of synthetic or highly refined bearing lubricants. Six other good load reducing opportunities are highlighted from a review of over 50 alternatives for hoisting and hauling in the mining industry.

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12-103	814.35	December 3, 1991	91-261-K

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EXECUTIVE SUMMARY

Introduction

It is estimated/1/ that hoisting and hauling in underground mines consumes 82 MW, or 31% of the total electricity consumed in underground mines. Individual mine hoists consume approximately 1 MW to 2 MW; therefore, even modest improvements in efficiency could provide significant load reduction at each site.

A study was performed to identify the alternatives available for hoisting and hauling in the mining industry. In particular, the study focussed on alternatives that could have some impact on the electricity consumption.

Methodology

The information for this study came from various sources; a literature review, contacts with manufacturers, contacts with government and industry associations, contacts with research organizations, and contacts with mining companies. Additionally, a preliminary summary table was prepared and reviewed by a number of contacts in the mining industry. The feedback from these reviews has been incorporated in this report.

Key Results from the Study

The study identified over 50 different alternatives for hoisting and hauling, which could impact the electricity consumption. The alternatives which were reviewed included the conventional alternatives, as well as newly available techniques, and techniques still under development. The alternatives with the most potential for load reduction are summarized in Table 1. Table 1 also notes whether the load reduction opportunity can be sought pro-actively, or conditionally. A conditional approach means that active involvement by Ontario Hydro will not be effective until the opportunity arises at a mine site. This distinction is made because hoisting and hauling facilities are permanent fixtures in mines, and the possible energy savings alone are not enough to justify the replacement of existing equipment.

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Table 1 - Demand Management Opportunities for Hoisting and Hauling in the Mining Industry				
System	Opportunity	Impact on Electricity Consumption[1]	Priority of opportunity [2]	Pro-active or Conditional Approach
Hoist	replace motor-generator sets with thryristor power supplies	3 MW reduction (total potential)	1	conditional
	use synthetic lubricants in hoist bearings	3 MW reduction (total potential)	1	pro-active
	replace old motors with high efficiency ac motors and cycloconverter power supplies	N/A	3	conditional
Conveyors	replace old motors with high efficiency motors	N/A	1	pro-active
	replace mechanical torque converters (fluid couplings) with electronic variable speed drives	≈5% reduction in electric consumption	2	pro-active
Underground trucks and locomotives	use high efficiency chargers with battery powered vehicles	240 kW reduction (total potential)	1	pro-active
	shift battery charging to off-peak	N/A	1	pro-active
	for hauling on grades, use trolley powered vehicles[3] with regenerative braking	N/A	2	conditional

Recommendations

To a large extent, the best load reducing alternatives for hoisting and hauling in mines (listed in Table 1), are covered in existing energy management programs (eg, high efficiency motors, off-peak-charging, etc). The existing programs therefore represent the least expensive approach to these load reducing alternatives.

Acknowledgement

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[1] N/A - not enough information available to estimate the load reduction

[2] 1-3 represents highest-lowest priority (priorities are estimated based on load reduction potential and comments received in surveys).

[3] power for trolley vehicles provided through overhead conductors

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TO MR. J.E. MITCHELL
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A REVIEW OF HOISTING AND HAULING ALTERNATIVES IN THE MINING INDUSTRY

1. INTRODUCTION

It is estimated /1/ that underground mine hoists in Ontario consume 58 MW, and electric vehicles used for underground hauling consume 24 MW. Since the hoisting and hauling load is spread over a small number of sites (approximately 30 mines) even modest efficiency improvements could result in significant savings at each site.

The objective of this study was to list the alternatives that are available, or being developed, for hoisting and hauling in the mining industry. The alternatives considered were limited to those which could have an impact on the consumption of electricity.

The study involved a literature search, and a phone survey of manufacturers, research organizations, mining companies, industry associations, and government mining offices. The people and organizations contacted for this project are listed in Appendix A. After a preliminary summary was prepared, comments were solicited from a number of contacts in the mining industry and their feedback was included in this report.

2. HOISTING IN THE MINING INDUSTRY

2.1 Background

The hoisting of men, materials and equipment in mines has developed to the point where it is quite efficient. However, there are some new developments in the design of hoist systems and components which may improve the hoisting efficiency.

Since there is a high capital cost associated with a mine hoist, the hoist is essentially a permanent fixture in a mine. The opportunities to implement load reducing alternatives primarily occur with the installation of new shafts. The other time that a change to the hoist may be considered is when mine production needs to be increased and the following options have been utilized;

1) increasing the number of operating hours per day for the mine,
2) increasing the payload of the hoist, and
3) increasing the hoist speed.

2.2 Description of Hoists Currently Operating in Ontario

The hoists being used in Ontario mines have a number of similar components which are illustrated in Figure 1. Hoist motors can be either dc or ac, and depending on the motor speed, a gear box may be used to provide speed reduction. The hoist will be attached to either a skip (for hoisting ore), a cage (for hoisting men and equipment), or a counterweight. The friction brake shown in Figure 1 is used for normal operation and is also available for emergency operation. In addition to friction braking, regenerative braking is used for normal hoist operation. Regenerative braking puts energy back on the electrical system during the braking cycle.

A list of the hoists used in Ontario mines is provided in Appendix B, along with the type of hoist, hoist payload, hoist power consumption and general mine information. The information was summarized from the 1991 Mining Sourcebook (published by the Canadian Mining Journal).

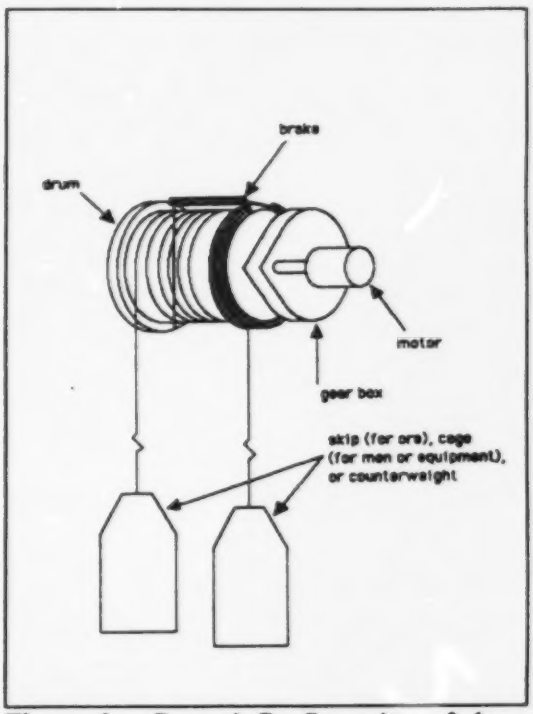

Figure 1 - General Configuration of drum hoist

2.3 Alternatives for Hoisting

There are a number of alternatives for mine hoists which involve both the hoist system and hoist components. The hoisting alternatives are described below and summarized in Table 3.

2.3.1 Alternative Hoist Systems

There are two general types of hoist systems in operation; the drum hoist and the friction hoist. With the drum hoist, the hoist rope is stored during the hoisting cycle. On the friction hoist, the rope passes over the wheel during hoisting. In addition to the traditional drum and friction hoists, there are a number of alternative systems which can be used. Brief descriptions are provided below of the traditional drum and friction hoists, along with the various alternatives for hoist systems.

i) Drum Hoist

The two main types of drum hoists are the single drum and double drum. The single drum hoist has one winding drum and can service either multi-level shafts with a single skip or cage, or single level shafts with the two skips or cages.

The double drum hoist has two drums along the same shaft which can be driven separately using one or two clutches. The double drum is primarily used for multi-level hoisting with two skips or cages.

ii) Friction Hoist

The friction hoist has a rope passing over the hoist wheel, and the friction between the rope and the drum provides the rope tension required to lift the payload. A sketch of a friction hoist is shown in Figure 2. A friction hoist will have a tail rope below the skips so that the ropes do not present an unbalanced load. Since the skips balance each other, the only out-of-balance load being lifted by a friction hoist is the payload (ore). The friction hoist is therefore the most efficient hoist system available. Typical efficiencies of various traditional hoist systems (from reference /2/), are summarized in Table 2.

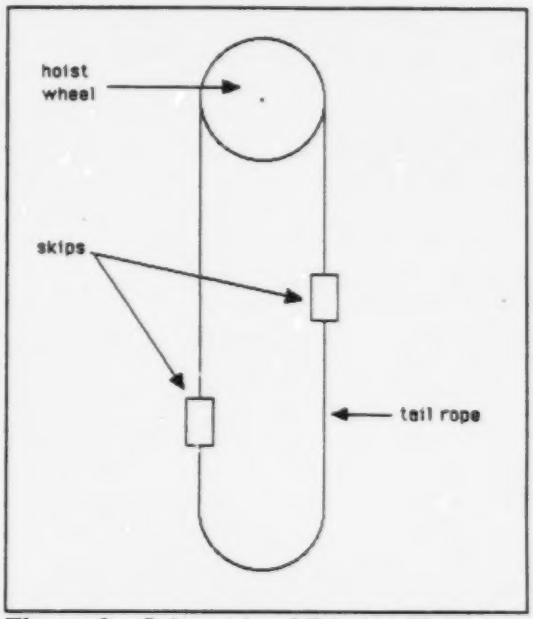

Figure 2 - Schematic of Friction Hoist

Table 2 - Typical Efficiencies of Mine Hoist Systems /2/	
Hoist System	System Efficiency
Friction - 2 skip	80%
Balanced drum - 2 skip	79%
Balanced drum - 1 skip	76%
unbalanced - 1 skip	71%

iii) Hydro hoist

A hydro hoist system uses water flowing through a pipe loop to lift the ore. The crushed ore is injected into the flow at the bottom of the shaft and is carried to the surface where it is separated from the water. The water is able to lift the ore because the water velocity exceeds the critical speed of the ore. The critical speed is the maximum speed that would be reached if a piece of ore was dropped in still water. A sketch of a hydro hoist system is shown in Figure 3.

The main application for the hydro hoist has been hoisting of coal. The hydro hoist has been used in Japan (coal, 100 tons/hr, from 515 m), Germany (coal, 450 tons/hour, from 365 m depth, 2100 kW), Spain (coal, 50 tons/hr from 507 m) and South Africa (quartzite fines, 15000 tons/month from 2200 m)/3/.

Since the efficiency of a motor/pump combination will not be greater than 85%, when all the other losses in the system are considered along with underground crushing and separation at the surface, it is not likely that a hydro hoist system will provide any load reduction. The main electrical advantage in the hydro hoist is an improvement in the load factor, since the pumps would run continuously.

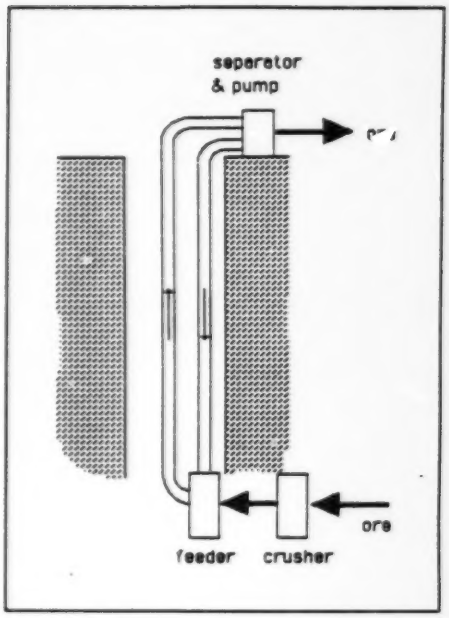

Figure 3 - General Configuration of a Hydro Hoist

iv) Air-Lift Hydro Hoist

A variation on the hydro hoist is the air-lift hydro hoist, which uses air injected with the ore to reduce the pumping power required. However, power will be required to compress the air to a pressure which at least exceeds the head of water in the pipe. Research is ongoing at the U.S. Bureau of Mines to compare the efficiency of the air-lift hydro hoist, with a hydro hoist. An air-lift hydro hoist has been used at coal mines in the U.S.S.R. (discussed in /3/), however the cost of the compressed air made the system very expensive. A sketch of an air lift hydro hoist system is shown in Figure 4.

v) Pneumatic Lifts

A pneumatic lift is conceptually described by Black /4/ for hoisting from depths greater than 5000 metres. The pneumatic lift was described as a technique for lifting platforms with ore. The required air pressure for lifting 100 tons was specified /4/ as 69 KPag. Black estimated that the power required for a pneumatic system would be 20% less than a friction hoist lifting the same amount of material. However, a very optimistic efficiency of 75% was assumed in the calculation for converting electricity into the work provided by the compressed air. Since the efficiency is more likely to be less than 10% (using tables in /5/), the pneumatic hoist would not be more efficient than a rope hoist.

2.3.2 Control of Hoist Motor Input

Mine hoists are driven by either dc or three phase ac induction motors. Traditionally, the constant torque characteristic of the dc motor has made it easier to control, while control of ac motors for constant torque has been more complicated. The techniques available for controlling the power supply to the motors are briefly reviewed below.

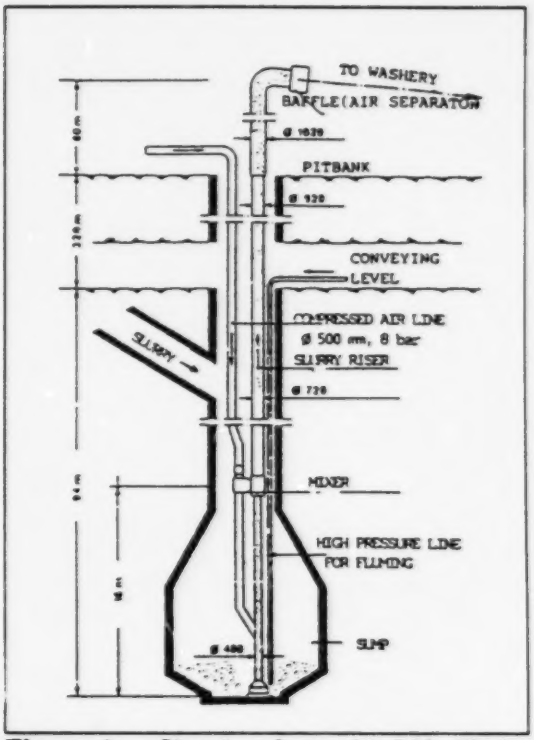

Figure 4 - Sketch of an Air-Lift Hydro Hoist

i) Control of dc Motors

Speed control of dc motors is achieved by varying the applied dc voltage. The dc voltage can be controlled by either a motor-generator (M-G) set or a static (thyristor) drive. Both the M-G set and the static drive can provide regenerative braking, which will return energy back to the electrical system during braking. Regenerative braking will therefore reduce the average electrical energy used by the hoist over a hoisting cycle.

The M-G set consists of a dc generator driven by an ac motor. The dc output voltage is proportional to the generator speed, and the generator speed is controlled by the generator field excitation. The efficiency of the M-G set is approximately 92% /6/.

The static (thyristor) drive consists of a transformer, a static converter, and protective and smoothing reactors (if required). The transformer converts the supply ac voltage to the necessary voltage for the static converter. The static converter rectifies the signal and conducts for the portion of the ac signal necessary for the required dc voltage. Smoothing reactors may be provided to reduce the ripple in the dc signal, and the protective reactors protect the converter from current surges, short circuits, and ac power losses. The efficiency of the static drive is approximately 98% /6/.

The mining industry is gradually changing from the M-G sets to the static drives, however it was estimated /7/ that there are still 29 M-G sets installed which represent approximately 50 MW. The load reduction that could be achieved by converting the 29 M-G sets to static drives is about 3 MW.

ii) Control of ac Motors

The torque provided by ac hoist motors is typically controlled by varying the current to the wound rotor, using a series of external resistors. However, the losses in the resistors lower the efficiency of the ac motor /2/ during periods of acceleration.

A more recent development in ac motor control is the cycloconverter. The cycloconverter is a thyristor converter which operates without a dc link circuit, and provides an output frequency from zero to half of the input (line) frequency. The output waveform to each of the three motor phases is constructed by selectively firing the thyristors to provide the necessary voltage throughout the output cycle. The main

advantage of the cycloconverter is that it allows a hoist to efficiently use an ac motor, which has a higher peak efficiency than a dc motor.

iii) Control of Hoist Operation

The operation of a hoist has traditionally required an operator. However automating the operation of the hoist has been used to increase the efficiency of the hoist (ie. tons of ore lifted per hoist). Programmable logic controllers (PLCs) have been used to make hoist operations smoother and quicker at a Placer Dome mine, with the result that the number of skips hoisted per 8-hour shift increased from 127 to 152 /8/. PLCs have also been used by Noranda to optimize the travel route for cages in a multi-level shaft /9/.

2.3.3 Hoist Motor Alternatives

As discussed in the previous section, the two types of motors used for mine hoists are ac induction and dc motors. The dc motors are either low speed direct drive, or high speed with geared speed reduction. The high speed dc motors have efficiencies of 93.6% /2/, and the direct drive dc motors have efficiencies of 91.5%. However, when the gearing transmission efficiency is factored in, the net effect is that both options have comparable efficiencies. By comparison, the ac direct drive motors have efficiencies of 94.6% /2/.

A variation on the ac motor is the integrated drive hoist produced by Siemens. The integrated hoist incorporates the rotor of the ac motor into the wheel of the friction hoist (shown in Figure 5). The integrated hoist has less mass and requires less space. It also tends to be more economical than traditional friction hoists in mine shafts requiring hoists larger than 3 MW /10/. The lighter mass will tend to reduce the electrical demand during acceleration. However, with regenerative braking, most of the power saved during acceleration would have been recovered during braking anyway. Therefore the electrical impact of the integrated drive will not be significant.

Another motor alternative that has been proposed /11/ is a linear induction motor with the armature supplied by a coaxial transformer. The configuration of the linear motor hoist is shown in Figure 6. The main advantage to the linear motor is that it does not require ropes for hoisting skips and cages. The lack of ropes will be a benefit in servicing very deep shafts and multi-level shafts. However, for the depths of currently used mine shafts, it is unlikely that linear motors will result in reduced power consumption /12/.

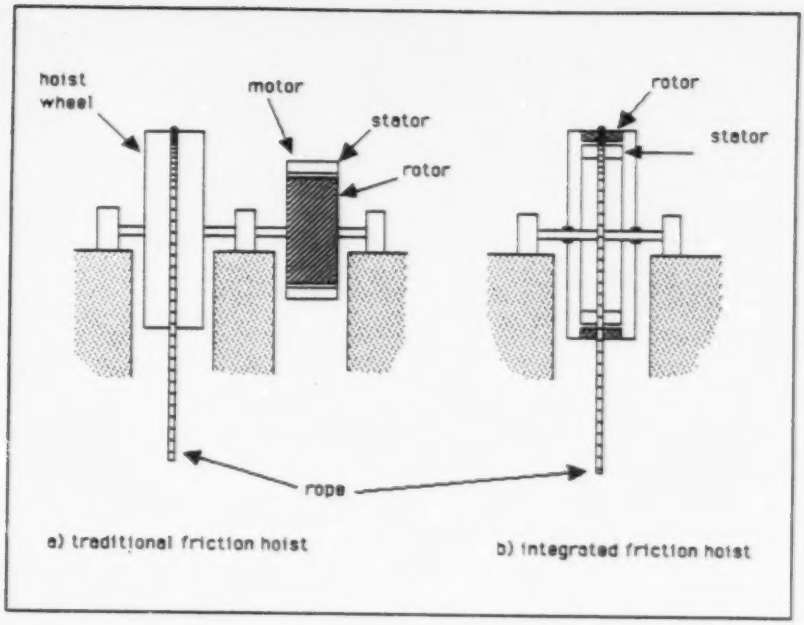

Figure 5 - Configuration of Traditional and Integrated Drive Friction Hoist

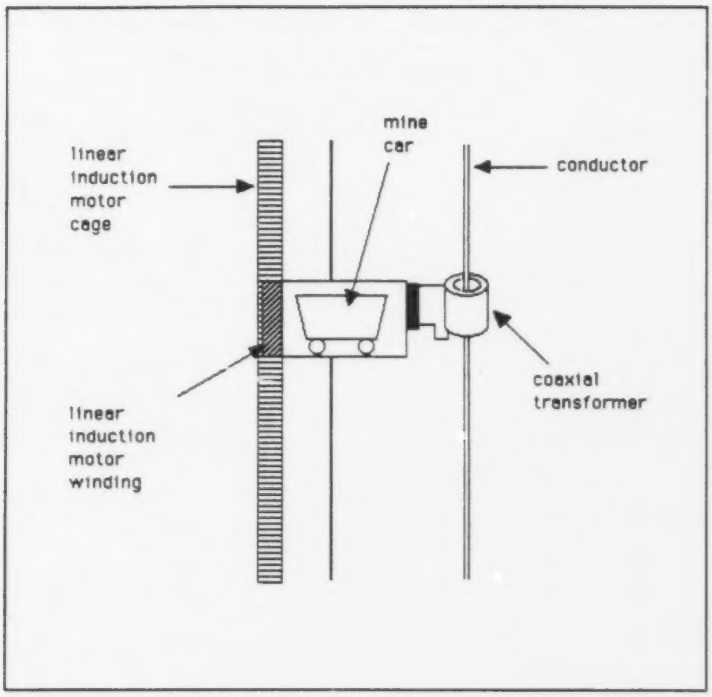

Figure 6 - Linear Motor for Mine Hoist

2.3.4 Bearing Alternatives

The main types of bearings used with mine hoists are journal and roller bearings. Journal bearings support the shaft on a thin layer of oil, while roller bearings utilize cylinders in rolling contact with the shaft. In terms of the electrical impact, the main difference between the two bearing types is the power required to overcome the starting torque.

Journal bearings may lose the oil layer after idle periods, and either require a high starting torque or an oil pump to restore the oil layer. Alternatively, the starting torque of roller bearings is similar to the running torque. One problem with roller bearings is that they are difficult to maintain or repair. A roller bearing alternative that will allow easier maintenance is the split roller bearing /13/. Split roller bearings have all their components divided across the shaft center, and thus allow better access for maintenance.

Another option for the bearings is the choice of lubricant. The use of a highly refined lubricant or synthetic lubricant can reduce the energy consumption by 3% to 8% /14/. The total potential load reduction provided by the appropriate lubricant selection would be approximately 3 MW.

2.3.5 Alternatives for Hoist Skips

The hoist skip is the container which is used to hold the ore during hoisting. The main alternative for hoist skips which impacts the electricity consumption is the use of lighter skips (discussed in /15/). Lighter skips utilize lighter materials which allow the payload to be increased without significantly increasing the power consumption. While this does not reduce the power consumption, it does avoid anticipated load growth.

A problem that has occurred with light skips is the corrosion caused by contact of non-similar metals. This problem is causing INCO to switch back to traditional skips /16/. The corrosion problem would therefore have to be solved before lighter skips could provide long-term improvements in hoisting efficiency.

2.3.6 Alternatives for Hoist Ropes

The currently available choices for hoist ropes include slightly different variations on steel ropes (eg. round strand, flattened strand), and multiple versus single ropes. To a large extent, the differences in the steel ropes do not have a significant effect on the power consumption of the hoist /4/.

One option that is being looked at by the U.S. Bureau of Mines /17/, is the potential to use Kevlar ropes, which would be significantly lighter than steel ropes. The weight of steel ropes can typically be about 25% of weight of the payload. The power savings with Kevlar ropes would occur with drum hoists, and particularly unbalanced single drum hoists. However, regenerative braking will diminish the power savings from lighter ropes.

Two factors that will affect the implementation of Kevlar ropes are:

1) the ability of Kevlar ropes to withstand abrasion, and
2) the availability of a technique for in situ inspection of the ropes.

2.3.7 Alternatives for Braking

In the normal operation of a hoist, the two types of braking systems used are friction brakes and regenerative braking. Friction brakes dissipate energy in the form of heat, whereas regenerative braking will put the energy back on the electrical system. The effect of regenerative braking is that any component that changes the inertia of the hoist will have a negligible effect on the average electricity consumption because the extra energy required during acceleration is returned to the electrical system during braking.

TABLE 3 - SUMMARY OF ALTERNATIVES FOR HOISTING IN THE MINING INDUSTRY

	Alternatives	Comments on Electrical Impact and/or efficiency	General Comments
Hoist Systems	Conventional ·single drum		·less expensive than double drum for single level or single skip/cage and counterweight /23/ ·used for multi-level, two-skip hoisting /23/
	·double drum ·friction Koepe	·smaller out-of-balance load on hoist means rms kW required per ton of payload is less than drum hoists /23/	
	Prospective ·hydro hoist	·better load factor but will likely use more energy over the hoisting cycle	·provides continuous hoisting ·pipe wear is a concern ·may be best suited to providing marginal increases in hoisting capacity
	·air-lift hydro hoist	·compressed air requirement will cause lower efficiency than hydro hoist	·applications in USSR are costly because of amount of compressed air required /3/
	·pneumatic lifts	·claims of energy savings /4/ are based on optimistic air compressor efficiencies	
Control of Motor Input	Conventional ·motor/generator sets	·efficiency ≈ 92% /6/ ·contributes to power factor improvement, leading p.f. with synchronous motors /23/	
	·thyristor static drive (DC)	·efficiency ≈ 98% /6/	·harmonics may interfere with mine commmunications
	Recently Available ·cycloconverter	·allows hoist to use more efficient AC motor	·economics better with hoists larger than 1.5 MW
Motor	Conventional ·DC	·efficiency ≈ 92% /2/	
	·AC	·efficiency ≈ 95% /2/	
	Recently Available ·linear motors	·eliminates ropes, but not likely to decrease power consumption	
	·integrated drive	·less mass contributes to higher efficiency	·economics better with hoists > 3 MW /10/

Bearings	Conventional ·journal bearings ·roller bearings Recently Available ·split roller bearings ·synthetic or highy refined lubricants	· synthetic lubricants and highly refined lubricants can reduce energy consumption by 3% to 8% /14/	·high starting torque after long idle periods ·starting torque not much greater than running torque ·allows easier maintenance and lubrication which could ultimately lead to better efficiency and broader acceptance of roller bearings
Skips	Recently Available ·light weight skips		·lighter skips provide an effective way to increase hoist capacity /14/
Ropes	Conventional ·single steel rope ·multi-rope friction drum Prospective ·synthetic fibre rope (eg. Kevlar)	·smaller drum diameter means less inertia for motor to overcome during acceleration, therefore marginally better load factor ·lighter rope will allow more mineral to be hoisted per kW (benefit somewhat offset by regenerative braking)	·for the same load, smaller rope diameter required, therefore drum diameter smaller
Hoist Controls	Conventional ·manual Recently Available ·automatic	·automatic controls allow the hoist capacity to be increased without increasing the size of the motor, however energy consumption will increase	·in one mine automatic controls increased the number of skips hoisted from 127 to 152 per 8 hr. shift /8/ ·automated cage hoists will select optimum routes given the starting points and destinations /9/
Brakes	·friction brakes ·regenerative braking	·puts energy back on the electrical system	·dissipates energy as heat

3. HAULING IN THE MINING INDUSTRY

3.1 Background

Hauling in the mining industry refers to the non-vertical transport of ore, equipment and men. The distance of haulage can vary from less than 100 m to many kilometres. The objective of this section is to review the techniques available for hauling in the mining industry. Emphasis is placed on the techniques whose primary function is hauling (eg. load-haul-dump vehicles not included).

Hauling is used in both open pit and underground mining, however the mining technique usually puts unique demands on the hauling alternative used. In open pit mining, hauling is used to transport ore and/or waste to a crushing plant or a dump. In underground mining, hauling is used for:

1) surface transportation of ore to a processing plant or loading point (eg, dock),
2) transportation of people in and out of the mine,
3) transporting ore from the ore face to the hoist,
4) haulage through a drift (a drift is a horizontal passage underground which follows the ore vein, and usually has a relatively small cross section).

The main techniques used for hauling in Ontario mines include belt conveyors, locomotive driven rail cars, and trucks. The hauling techniques currently used are summarized in Appendix C for the various underground and open pit mines in Ontario.

3.2 Alternatives for Hauling

There are a number of alternatives for hauling in the mining industry which are described in the following section. A summary of the alternatives is provided in Table 5.

3.2.1 Belt Conveyors

Belt conveyors are generally used in high volume, long distance applications. They can handle steep grades (in some cases, vertical haulage), and they use up to **80%** /18/ of the energy consumed for payload transportation. The main disadvantages of conveyors are:

1) they are relatively difficult to move in most cases,
2) they have a high capital cost, and
3) they require the rock to be broken into fairly small pieces (to provide a good belt life).

Although conveyor belts are energy efficient compared to other hauling techniques, the technologies they could replace are largely diesel driven (with the exception of electric trolleys). Therefore, conveyor belts themselves will not likely present a significant load reduction opportunity. However, there are a number of factors in the selection of a conveyor belt that may minimize the electricity consumption of a belt conveyor.

3.2.1.1 Power Losses in Conveyor Systems

In addition to the power losses in the motor and the drive transmission, conveyor systems have a number of sources of frictional resistance in the load, belt, and belt support. The frictional resistance in the conveyor system will consist of the following components /19/:

1) resistance of the idlers to rotation
2) sliding resistance between the belt and idlers
3) resistance of the belt to flexure as it moves over the pulleys
4) resistance of the load to flexure as the belt and load move over the idlers
5) resistance of the belt to flexure over terminal and bend pulleys
6) resistance of terminal and bend pulleys to rotation.

3.2.1.2 Alternatives for Conveyor Belt Systems

A number of conveyor alternatives are discussed below. Unfortunately, data regarding the load impact of the alternatives are generally not available. However, where possible the load impact is discussed qualitatively with regard to the sources of power losses listed above.

i) Motor Selection

In a typical application, a conveyor will run continuously at the same speed, and therefore flexibility in the speed of operation is not a concern. The main criteria in the selection of a motor is the starting torque or the in-rush current resulting from starting the conveyor. Three techniques that are used to deal with the starting torque are:

1) using a reduced voltage start to avoid the in-rush current,
2) using a wound rotor motor (and control torque with rotor current),
3) using a mechanical torque converter (ie. fluid coupling), and
4) using an electronic variable speed drive.

The reduced voltage start and the wound rotor motor will have poor efficiencies during the starting cycle for the conveyor. However, in applications where the starting cycle is insignificant compared to the time running at full power, the reduced voltage start or wound rotor will provide the most efficient alternative overall.

In shorter conveyors, it is possible that there could be a number of starts and stops during a shift. In these circumstances, the fluid coupling or the electronic variable speed drive would become a consideration. Fluid couplings however have peak efficiencies of 90% /5/, whereas electronic variable speed drives have efficiencies of approximately 95% to 98%. Therefore, the electronic variable speed drive provides the most efficient alternative.

In all the above cases, high efficiency motors will also provide a reduction in the electricity consumption of conveyor systems.

ii) Speed Reduction from Motor

In most conveyors, the drive pulley will not run at the same speed as the motor shaft. Therefore motor speed reduction is often necessary and the drive transmission represents another opportunity for minimizing losses. Some of the available speed reduction techniques are listed in Table 4 along with their transmission efficiencies. Where possible or necessary, the single reduction helical or herringbone gear will provide the best efficiency.

Table 4 - Mechanical Efficiencies of Speed Reducers for Conveyor Belt Drives (from /19/)	
Speed Reduction Mechanism	Approximate Efficiency
single reduction helical or herringbone gear	95%
V-belts and sheaves	94%
roller chain and cut sprockets, open guard	93%
roller chain and cut sprockets, oil tight enclosure	95%
low ratio (up to 20:1) worm gear	90%
high ratio (greater than 60:1) worm gear	50%
spur gears - cut - cast	90% 85%

iii) High angle conveyors

High angle conveyors, such as Sandwich and Flexowell® conveyors, allow materials to be moved at very steep angles (up to 90°). The Sandwich conveyor uses two rubber belts to Sandwich the material and prevent it from sliding backward /20/. The Flexowell® conveyors consist of a belt with flexible sidewalls and cross cleats that effectively create buckets on the belt, and allow the material to be lifted vertically /21/. The Sandwich and Flexowell® conveyors are illustrated in Figure 7.

The Sandwich and Flexowell® conveyors are used when the conveying angle is greater than 20° (the maximum angle for a standard conveyor). Therefore, they could result in shorter conveyors and reduced power losses in the idlers.

iv) Pipe Conveyor

The Pipe Conveyor is a conveyor belt system where the idlers curve the cross section of the belt around 180° (shown in Figure 8) /22/. Since the cross section of the belt is circular, the pipe conveyor can also negotiate gentle corners (radius > 45 m) without requiring material transfers.

The primary benefit of the pipe conveyor is its ability to minimize dust. Therefore in an underground mine it could help to minimize the ventilation requirement and allow a faster conveyor speed with fine materials. Also, the ability of the pipe conveyor to negotiate gentle corners may reduce the number of transfer points and thus minimize the power losses in the pulleys. However, the additional belt flexure losses around the pulleys will offset some of these power savings.

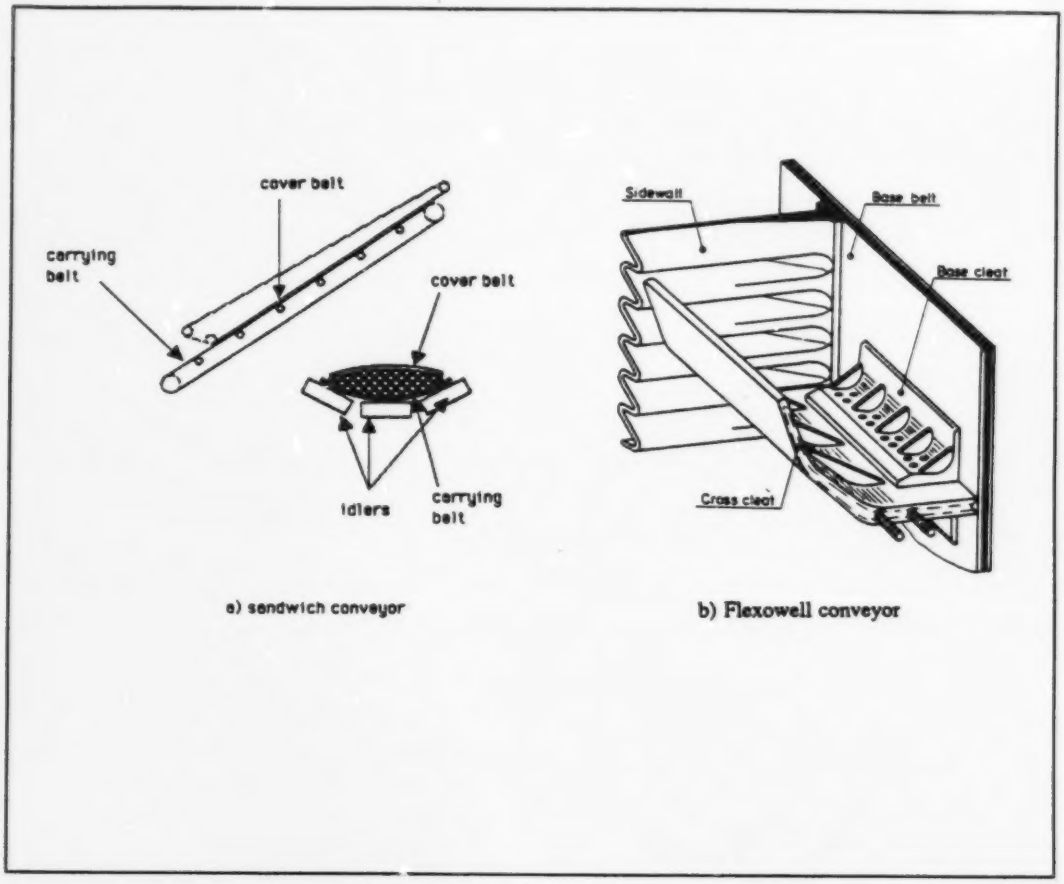

Figure 7 - Conveyors for High Angle Conveying

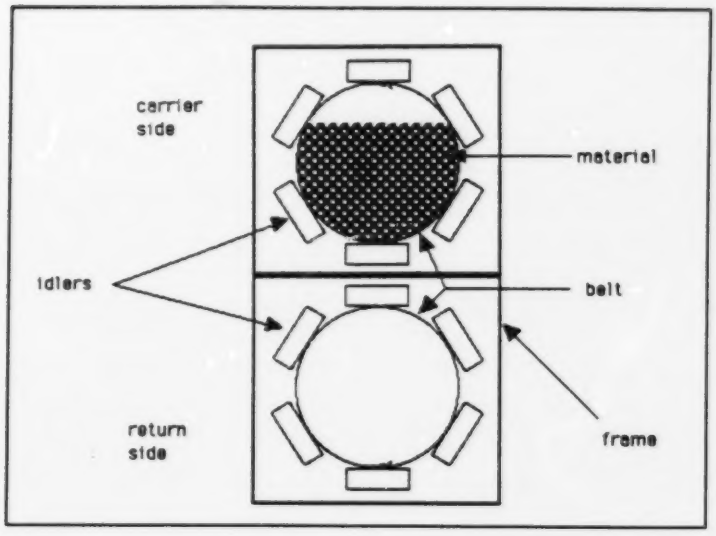

Figure 8 - Section of a Pipe Conveyor

v) Synthetic Fibre Reinforced Belt

A lighter conveyor belt material is available which uses aramid fibres to replace the steel cable in standard belts /23/. The fibre reinforced belt is approximately half the weight of the steel cable reinforced belts. The lighter belt is claimed to reduce the power requirements of the conveyor system. Using some typical loadings listed in /24/, the weight reduction may represent about 10% of the total weight (belt plus load) on the idlers. A further benefit of the lighter belt is that it is claimed to be more wear resistant.

The power savings from the lighter belt weight will be somewhat offset by the increased flexure losses in lighter belts. There is not enough information to assess this tradeoff, but flexure losses can be a large component of the power requirement. From an example for a horizontal conveyor in "Belt Conveyors for Bulk Materials" /19/, the power lost due to flexure in the belt and load was about 3/4 of the power requirement.

iv) Regenerative Conveying

In conditions where the discharge end of the conveyor is sufficiently lower than the loading end, the load can be used to produce, rather than consume power /24/. Regenerative conveyors are particularly effective in the surface conveyance of high tonnages over adverse terrain.

v) Bearing Lubricants

Bearings are used in a number of locations in a conveyor system, such as the main drive, the terminal pulleys and the idlers. By using highly refined lubricants or synthetic lubricants, it is possible to save 3% to 8% in the electricity consumption /14/.

3.2.2 Underground Tracked Haulage

The list of hauling techniques at Ontario's underground mines (in Appendix C) shows that many mines use a combination of belt and tracked (rail) haulage. Even if a conveyor belt is used to move the ore from the ore face to the surface, tracked haulage will still be needed for transporting people and equipment.

The locomotives pulling the mine cars can be powered by a number of sources: diesel, battery, trolley (ie, power from electrical conductor), compressed air, and cables (ie, winches). In Ontario, the types of locomotives used are primarily diesel, battery, and trolley. The different types of locomotives are described below with respect to their electrical impact.

i) Diesel Locomotives

The main electrical impact of diesel locomotives comes from the demand they put on the ventilation fan. However, the diesel exhaust is only part of the ventilation requirement and therefore only accounts for a marginal increase in the ventilation power requirement. For example, a recent study /1/ estimated that if all the underground diesel load-haul-dump vehicles were replaced by electric vehicles, the ventilation savings would be 10 MW, but the additional vehicle load would be 150 MW.

ii) Electric Locomotives

Electric locomotives have the advantages that they do not put additional demand on the ventilation system, and they are also less costly to maintain. Electric locomotives can get their power from either batteries or an overhead trolley line.

The main alternative that could impact on the electricity consumption of battery powered locomotives is in the choice of battery charger. The efficiencies of the different types of battery chargers vary from 80.2% (Ferroresonant) to 89% (Switch-Mode high frequency charger). A detailed test report on the various battery charger alternatives is provided in /25/.

Since power for trolleys is provided through overhead conductors, trolleys avoid the energy conversion losses associated with batteries. Additionally, in downhill sections of track, trolleys can be used to put electricity back on the grid.

Overall, trolleys will require less energy than battery systems. However, battery powered locomotives provide the potential for off-peak charging.

iii) Compressed Air Locomotives

Compressed air locomotives use air stored in a receiver mounted on the locomotive. Since the storage capacity is limited, they can only be used for short runs (eg. < 100 m). However, the conversions of electrical power into compressed air, and compressed air into mechanical work are quite inefficient. Therefore, compressed air locomotives represent an inefficient use of electricity.

iv) Cable Driven Cars

Another method for driving rail cars uses a winch to pull the cars. Since the cars do not have to carry motors, transmissions, or batteries, this technique has the potential to be quite efficient. However there is no data available which compares the energy consumption of cable driven cars with respect to electric

locomotives. One feature that will usually be needed for this type of system is a rope guide system along the rails /26/.

v) Magnetic Levitation

The feasibility of using magnetic levitation (with permanent magnets) for hauling ore cars is being investigated at the U.S. Bureau of Mines /27/. The main motivation for the research is for improved safety of haulage in coal mines. However, like the linear motor for hoists, it is unlikely that magnetic levitation will be more efficient than the current hauling techniques.

3.2.3 Surface Tracked Haulage

For surface tracked haulage, the main locomotive alternatives include diesel electric and electric. For the electric locomotive, the only load impacting alternative found was the choice of supply voltage. It was indicated /24/ that in order to supply 1500 V for longer track distances (as opposed to 750 V) the initial cost will be 10% to 20% higher. Depending on the current used and the conductors used, the high voltage transmission may provide an energy saving alternative.

3.2.4 Trackless Haulage

Trackless haulage in mining primarily includes diesel trucks for open pit mining, and trucks and shuttle cars for underground mining. Since the diesel trucks used for open pit mining will not have an impact on electricity consumption, the discussion below focuses on shuttle cars and underground trucks.

i) Shuttle Cars

A shuttle car is a self-propelled rubber tire vehicle designed for underground mining. The cars travel back and forth between the advancing ore face and the dumping (or transfer) point, without having to turn around. The shuttle cars are either cable driven, battery powered, or diesel powered.

The cable driven shuttle car is powered from the standard mine electrical supply, and therefore saves on the conversion losses associated with battery powered cars. The battery powered cars also have the additional weight of the battery to transport; however battery powered cars allow considerably more flexibility in the route used.

As with battery powered vehicles discussed above, the choice of an efficient battery charger, and off-peak charging represent the best demand management opportunities for shuttle cars.

ii) Underground trucks

The trucks used in underground mines are similar to the surface trucks used except they have additional exhaust scrubbers, and they have lower profiles. Underground trucks are powered by either diesel engines, batteries, or trolleys /28/.

An alternative for underground trucks which uses a combination of trolley and battery power, is the Kiruna Electric system. Hauling with the Kiruna system is powered by the trolley line, however the battery supply allows the trucks to temporarily leave the trolley supply and permit passing of trucks. This provides most of the flexibility of battery powered trucks, and the energy efficiency of a trolley system.

The Kiruna trucks can be used on grades up to 17% /27/, and regenerative braking is an option for the trucks on declining grades. The vehicles are claimed to have an energy utilization factor of 80% /29/.

3.2.5 Hydraulic Pipeline Haulage

In hydraulic pipeline transport, the ore is pumped in a slurry of ore and water. In general, underground hydraulic haulage is only economically feasible on steeply pitching seams of a friable material. Applications of hydraulic transport have mainly been in the coal industry. Considering the pipeline losses and the pump losses, hydraulic transport will not likely be any more efficient than trolley powered trucks or shuttle cars.

3.2.6 Aerial Tramway Haulage

An aerial tramway transports loads using carriers suspended from cables between fixed points. The tramway is used to traverse difficult terrain or cross wide natural obstacles without building bridges, tunnels, or roads. In situations where an aerial tramway would be considered, it is claimed /24/ to have a lower power consumption than the other alternatives.

TABLE 5 - SUMMARY OF ALTERNATIVES FOR HAULING IN THE MINING INDUSTRY

	Alternatives	Electrical Impact and/or efficiency	Comments
Hauling Systems	Conventional ·belt conveyors	·up to 80% of energy used for payload transport	·high volume, long distance, low unit cost, high initial cost ·requires material to be broken into small pieces
	·tracked hauling	·diesel locomotives may require additional ventillation underground	·high volume, long distance, low unit cost ·can not handle adverse grades > 3%
	·trackless hauling	·diesel trucks may require additional ventillation underground	·can handle large pieces of rock ·most flexible for handling changing mine faces and pit outlines
	·hydraulic	·has inherent inefficiencies /23/	·can negotiate steep ramps ·economically feasible only on steeply pitching seams of friable material (mainly coal applications)
	·aerial tramway	·relatively low power consumption in rough terrain /23/	·independent of geographical contours and obstacles
	Prospective ·magnetic levitation	·will likely be less efficient than the conventioanl alternatives /26/	·being developed as a safer alternative than conveyors for coal mines (ie. accidents during conveyor repairs and fires caused by overheated conveyor rollers)
Conveyor Systems	Conventional ·standard open belt	·up to 80% of energy consumed used for payload transportation /17/	·can handle grades up to 20°
	Recently Available ·steep angle conveyor	·steep haulage angles can minimize the conveyor length, and also the power requirement	·Sandwich and Flexowell conveyors permit conveying up to 90° (ie. vertical)
	·pipe conveyor	·could save on ventillation in transporting finer materials	·conveyor can negotiate gentle curves (radius > 45 m.), without transferring material
Conveyor Belts	Conventional ·steel reinforced		
	Recently Available ·synthetic fibre reinforced	·power reduction from lighter belt will depend on whether the belt stiffness is equivalent to steel reinforced belt (ie. for avoiding flexure losses)	·aramid fibre replaces steel for belt reinforcement /27/
Conveyor - Starting Controls	·mechanical torque converter	· fluid couplings have peak efficiencies of 90% /5/	
	·electronic variable speed drive	·efficiency ≈ 95%	

Conveyor - Speed Reduction	·helical/herringbone gears ·spur gear ·worm gear ·belt or chain drive	·helical or herringbone gears and chain drives in oil tight enclosures provide the highest efficiencies	·the efficiencies of the various options are summarized in Table 1
Conveyor - Bearing Lubricants	·synthetic lubricants and highly refined lubricants	·synthetic lubricants and highly refined lubricants may reduce the electricity consumption by 3% to 8% /14/	·savings will be conditional on accessibility of bearings (ie, many idlers are sealed)
Underground Tracked Haulage	·diesel locomotive ·battery locomotive ·trolley ·compressed air locomotive ·cable driven	·may increase ventillation requirement and fan power ·possible load reduction potential for different chargers as discussed in /24/	·low capital cost, higher haulage speed than electric locomotive ·power supplied through electric power rail ·very short runs (small drifts <100 m.) /23/ ·special track required to negotiate corners or changing inclines /25/
Surface Tracked Haulage	·diesel electric locomotive ·electric locomotive	·for long tracks, the losses at the lower voltages may be significant	·efficient (electric) transmission, low operating costs ·low maintenance costs ·power supplied by overhead lines at either 250, 500, 600, 750 or 1500 V /23/
Trackless Haulage	·trucks ·Kiruna trucks ·shuttle car - battery cars - diesel cars - cable-reel	·alternatives for battery chargers discussed in /24/ ·provides efficiency and regenerative braking of trolley with flexibility of battery powered trucks ·alternatives for battery chargers discussed in /24/ ·ventillation requirements may increase fan power	·diesel and diesel-electric powered for surface trucks, diesel and battery electric powered for underground ·mainly for handling supplies ·pathway limited to cable route

4. CONCLUSIONS

The current study reviews the scope of the alternatives available for hoisting and hauling in the mining industry.

Hoisting and hauling equipment tends to be permanent fixtures in mines. Therefore the opportunities to substitute load reducing alternatives mainly occur with the development of a new shaft, but also when the production of a mine is increased. Even when equipment is replaced, it must compete with second hand equipment which is inexpensive and readily available (eg, short delivery time).

From the long list of hoisting and hauling alternatives presented in this report, there are a number which are more interesting from a demand management perspective. These opportunities are reviewed below for both immediate and long-term application.

Immediate Demand Management Opportunities

Hoists

i) Replace the existing motor-generator sets with static thyristor drives to reduce the power consumption by approximately 6%. This has a total load reduction potential of 3 MW.

ii) Replace old motors with high efficiency motors and power supplies. Using alternating current motors with cycloconverters will use the least amount of electricity.

iii) Use synthetic lubricants and highly refined lubricants in hoist bearings to reduce electricity consumption by 3% to 8%. This has a total load reduction potential of 3 MW.

Conveyors

iv) Replace mechanical torque converters (fluid couplings) with electronic variable speed drives. This would provide a 5% reduction in electricity consumption.

v) Replace old motors with high efficiency motors.

Underground Tracked Haulage and Underground Trucks

vi) If hauling on grades is required, use trolleys to power the vehicles so that regenerative braking can be used to put energy back on the system.

vii) Using switch mode high frequency battery chargers could save 10% of the electricity consumption compared to ferroresonant chargers. With a total load of approximately 2.4 MW, the total load reduction potential of this opportunity is approximately 240 kW.

viii) Off-peak charging of the batteries for battery powered locomotives and trucks.

Long-Term Demand Management Opportunities

i) Current light skips have had problems with corrosion, however if the corrosion problem could be solved then they would provide improvements in the hoisting efficiency.

ii) If the mines in Ontario start looking at deeper mine shafts (eg. greater than 2000 m) standard rope hoists will be less effective. Therefore techniques such as hydro hoisting or linear motor driven hoists could provide more efficient hoisting alternatives.

5. RECOMMENDATIONS

A number of load reducing opportunities for hoisting and hauling are summarized in the Conclusions and Table 1 (executive summary). However, most of these opportunities are already covered in existing energy management programs. Therefore it is recommended that the load reducing alternatives be pursued through existing programs.

6. ACKNOWLEDGEMENT

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APPENDIX A

Contacts for Hoisting and Hauling in the Mining Industry

MANUFACTURERS

Hoists

1) John T. Hepburn (Ray Pillon, Andy Bunce)
2) Larco
3) ABB (David Banks, Barry Johnson)
4) Nordberg (John Olsen)
5) Ingersoll-Rand (Al Wareham)
6) General Electric (Serge Staccato)
7) Siemens Electric Ltd (David Williams)
8) Outokumper (Veikko Koskela)

Conveyors

1) Sullivan Strong Scott
2) Minpro
3) Piedmont
4) Rovern Mining Equipment
5) Scholtz-Flexowell
6) Ward Ironworks

Battery Locomotives

1) Continuous Mining
2) Nelmaco Eastern Ltd
3) Nelson Machinery Company
4) Wajax

INDUSTRY ASSOCIATIONS

1) Ontario Mining Association (Bruce Campbell)
2) The Mining Association of Canada
3) The Canadian Institute of Mining and Metallurgy
4) The Institute of Mining Engineers (England)
5) The South African Institute of Mining & Metallurgy

GOVERNMENT OFFICES

1) Energy, Mines & Resources (Vaughn Munroe)
2) Ministry of Northern Development and Mines
3) Ontario Ministry of Labour, Mining Health and Safety Branch (Mr. R.B. Sargeant)

RESEARCH CENTRES AND CONSULTANTS

1) U.S. Bureau of Mines (Terry Muldoon, George Bockosh)
2) HDRK Mining Research Ltd. (Ken Matthews)
3) Center for Materials Productivity, (Joe Goodwill, Terry McNulty)

ONTARIO HYDRO

1) Mel Harju (Northeastern Region CES)
2) Luke Frawley (Northeastern Region CES)

MINING COMPANIES

1) INCO (Joe Loring, Largo Albert)
2) Falconbridge (Mike Park, Ray Redcliff)
3) Noranda (Peter Lintern)
4) Placer Dome (Ed Sulis)
5) Johannesburg Consolidated Investment Company (Lester Napier), South Africa

APPENDIX B

Summary of Hoists at Ontario Mines

Hoists in Ontario Mines

Company	Mine/Location (minerals)	Daily Tonnage	shaft #/depth	Hoist type/make/power	skips/cages
American Barrick Resources Corp	Holt-McDermott/Kirkland Lake (Au)	1400	/420 m	DD/Nord/1340 kW	Norcast 9t/ Norcast 16 men 1-deck
Denison Mines Ltd., Uranium Division	Denison/Elliot Lake (U_3O_8, Y_2O_3)	14500	1/550 m 1/550 m 2/820 m 2/820 m 2/820 m	DD/CIR/1120 kW DD/CIR/930 kW DD/CIR/750 kW DD/CIR/930 kW DD/CIR/930 kW	/ Baycar 1-deck 25 men Baycar 9.5 t / / Baycar 2-deck 80 men Sala 12.5 t / Sala 12.5 t /
Dickenson Mines Ltd.	AW White/Balmerton (Au)	762	1A/1120 m 1B/1120 m 2 /730 m	SD/BN/600 kW DD/CIR/520 kW DD/CIR/520 kW	/DOL 2-deck 18 men Kimberley 4t / DOL 1-deck 9 men Rolachute 4.5 t / DOL 1-deck 9 men
Falconbridge Ltd.	Fraser/Onaping Falls (Ni, Cu, Co, Au, Pt, Pd, Cd)	2750	1/1580 m	DD/FH&B/2x930 kW	10 t / 2-deck, 2x35 men
Falconbridge Ltd.	Lockerby/Whitefish (Ni, Cu, Co, Pt, Pd)	1950	1/1320 m 2/1220 m	DD/FH&B/2x930 kW F/CGE/520 kW	Wabi 12t / Wabi 1-deck 16 men / 44 men
Falconbridge Ltd.	Onaping/Onaping Falls (Ni, Cu, Co, Au, Pt, Pd)	1300	1/1280 m 1/1310 m	DD/Nord/1860 kW DD/CIR/600 kW	DOL 11t / / Norcast 24 men
Falconbridge Ltd.	Strathcona/Onaping Falls (Ni, Cu, Au, Ag, Pt, Pd)	2000	1/1520 m 2/914 m 2/914 m 3/1520 m	DD/CIR/1860 kW F/ASEA/3300 kW F/ASEA/550 kW	/ Wabi 2-deck Sala 18t / / Wabi 1-deck 46 men Sala 18t /
Hemlo Gold Mines Inc.	Golden Giant/Hemlo (Au)	3000	/1145m /1145m	/Nord/3350 kW /Nord/750 kW	Rolachute 16t / / Dorr-Oliver 1-deck 44 men
Inco Ltd. Ontario Division	Copper Cliff North/Copper Cliff (Ni, Cu, Co, PM)	3000	1/1260 m 1/1260 m	DD/Nord/1490 kW DD/Bert/4325 kW	/ 1-deck 42 men 20t /
Inco Ltd. Ontario Division	Copper Cliff South/Copper Cliff (Ni, Cu, Co, PM)	4300	1/1295 m 1/1295 m	DD/FH&B/2050 kW DD/FH&B/2050 kW	/ 2-deck 84 men Rolachute 17 t /
Inco Ltd. Ontario Division	Crean Hill/Copper Cliff (Ni, Cu, Co, PM)	3000	/1250 m /1250 m	DD/Nord/2x820 kW DD/BN/1860 kW	10t / / 1-deck 44 men

Inco Ltd. Ontario Division	Creighton No. 7 & No. 9/Creighton (Ni, Cu, Co, PM)	8300	7/610 m 9/2160 m	DD/Nord/2x2050 kW DD/FH&B/5220 kW	15t / 16.5t / 2-deck 88 men
Inco Ltd. Ontario Division	Frood/Sudbury (Ni, Cu, Co, PM)	6300	/870 m /870 m	DD/Nord/750 kW DD/Nord/2390 kW	/ 1-deck 42 men 12t /
Inco Ltd. Ontario Division	Levack/Levack (Ni, Cu, Co, PM)	4400	2/ 2/ 3/	DD/Nord/890 kW DD/DE/2x2240 kW DD/CIR/890 kW	/ 1-deck 42 men 18t / / 1-deck 42 men
Inco Ltd. Ontario Division	Little Stobie/Sudbury (Ni, Cu, Co, PM)	3300	/760 m	KF/West/600 kW	12t / 1-deck 42 men
Inco Ltd. Ontario Division	Stobie/Sudbury (Ni, Cu, Co, PM)	10730	7/1230 m 7/1230 m 8/790 m	DD/Nord/820 kW DD/Nord/2x2240 kW DD/BN/2x2240 kW	/ 1-deck 42 men 14t / 15t /
LAC Minerals Ltd.	Macassa/Kirkland Lake (Au, Ag)	447	1/930 m 3/2210 m 1w/570 m 2w/525 m	DD/CIR/450 kW DD/Nord/2830 kW DD/CIR/220 kW DD/CIR/260 kW	DOL Kimberley 3t/DOL 1-deck 12 men DOL 9t / DOL 1-deck DOL Kimberley 2t/DOL 1-deck 12 men DOL Kimberley 2t/DOL 1-deck 12 men
Minnova Inc.	Winston Lake/Schreiber (Zn, Cu)	1100	/630m	/FH	6.5t / Norcast 15 men
Noranda Minerals Inc. Geco Div.	Geco/Manitouwadge (Cu, Zn, Ag)	4300	1/730 m 4/1310 m 4/1200 m	F/CIR/370 kW F/CWest/520 kW F/CWest/2800 kW	/ Wabi 1-deck / Wabi 1-deck 2 DOL 18t Rolachute /
Noranda Minerals Inc. Lyon Lake Div	Lyon Lake/Sturgeon Lake (Zn, Cu, Ag, Pb)	1500	/1240 m	DD/CIR/1490 kW	Wabi 8t / Wabi 12 men
Placer Dome Inc.	Campbell/Balmertown (Au, Ag)	1200	/1310 m /1310 m	DD/Nord/820 kW DD/Nord/335 kW	Wabi 5 & 6t / Wabi 1-deck 11 men Ctwt on 1 side/Wabi 2-deck 8 men/deck
Placer Dome Inc.	Detour Lake/Detour Lake (Au, Ag)	2530	/560m /570m	DD/CIR/480 kW DD/Rex/670 kW	/ 1-deck 48 men Sala 8.8t
Placer Dome Inc.	Dome/South Porcupine (Au, Ag)	4200	8/1650 m 8/1650 m 3/620 m	DD/O&K/560 kW DD/O&K/2610 kW /Nord/480 kW	/ DOL 1-deck 48 men DOL 16t / / DOL 1-deck 40 men

Rio Algom Ltd.	Quirke/Elliot Lake (U_3O_8)	7700	/380 m /690 m /690 m	/CIR/260 kW /CIR/1120 kW /CIR/2x1490 kW	/ DOL 1-deck 30 men / DOL 2-deck 70 men 2 DOL 15t /
Rio Algom Ltd.	Stanleigh/Elliot Lake (U_3O_8)	3110	/1280 m /1280 m	DD/JTH/4100 kW DD/JTH/1300 kW	2 DOL 22t / / DOL 2-deck 120 men
Teck-Corona Operating Corp	David Bell/Hemlo (Au)	1250	/340 m /1160 m	DD/CIR/670 kW DD/BN/1300 kW	/ Dorr-Oliver 2-deck 28 men DOL Lakeshore 7.7t /
Westrock Industries Ltd	Drumbo/Drumbo (Gypsum)	1000	/120 m	SD/O&K/150 kW	Sala 5t / Sala 10 men
Williams Operating Corp	Williams/Hemlo (Au)	6000	/1300m /1300m /1300m	/BN/5220 kW /BN/930 kW /BN/750 kW	DOL 22t / / 1-deck 58 men / 1-deck 9 men

Manufacturer

CIR - Canadian Ingersoll Rand
BN - Bertram Nordberg
FH&B - Fullerton, Hodgart & Barclay
GE - General Electric
Nord - Nordberg
Bert - Bertram
DE - Dominion Engineering
CWest - Canadian Westinghouse
Rex - Rexnord
O&K - Orenstein & Koppel
JTH - John T. Hepburn

Hoist Types

DD - Double Drum
SD - Single Drum
F - Friction

APPENDIX C

Summary of Haulage at Ontario Mines

Haulage at Underground Mines in Ontario

Company	Mine	Drift & Ramp Haulage	Trackless Haulage				tracked haulage			Transport from Underground Crushers to Hoist
			level	conveyors	rubber tired vehicles	length of haul	level	length of haul	type of locomotive	
American Barrick Resources Corp	Holt-McDermott	Drift - 4.5t locos & 1000 cu.ft. cars						300-1500 m		
Denison Mines Ltd., Uranium Division	Denison			1-1 m & 8-1.2 m belts, 5.2 km long	30t truck	90 m				1m conv 30m long
Dickenson Mines Ltd.	AW White	Drift - Hudson side dump cars						305-1520 m	battery	
Falconbridge Ltd.	Craig	Ramp - trucks	930 m & 1230 m		trucks	180 m	1230 m	1520 m		
Falconbridge Ltd.	Fraser		1040 m 1340 m		3 trucks 1 40t truck		1100 m 1400 m	1430 m 1690 m	battery trolley	
Falconbridge Ltd.	Lockerby				2 26t trucks 1 39t truck	305 m				0.7m conv 180 m long 0.7m conv 100 m long
Falconbridge Ltd.	Onaping	Ramp - Wagner 40t truck			40t truck	915 m	1160 m 1230 m	915 m 1830 m		1 m conv 46 m long
Falconbridge Ltd.	Strathcona						880 m 1400 m	760 m 2130 m		1.2m conv 270 m long 1.2 m conv 46 m long
Hemlo Gold Mines Inc.	Golden Giant				26t truck	250 m	4335'	500 m		1.5 m conv 40 m long
Inco Ltd. Ontario Division	Copper Cliff North		370 m & 1040 m				490 m	1220 m		1 m conv 210 m long 1 m conv 15 m long
Inco Ltd. Ontario Division	Copper Cliff South	Drift - truck		1 m belt, 180 m long	5 trucks	180 m	620 m 915 m	1980 m 305 m	trolley diesel	1 m conv 150 m long
Inco Ltd. Ontario Division	Crean Hill									1 m conv 450 m long
Inco Ltd. Ontario Division	Creighton # 3						525 m	305 m	trolley	1 m conv 160 m long 1 m conv 550 m long
Inco Ltd. Ontario Division	Creighton # 9						2130 m		diesel & battery	1 m conv 690 m long 1 m conv 290 m long 1 m conv 290 m long 1 m conv 290 m long
Inco Ltd. Ontario Division	Frood						305 m 430 m	305 m 1520 m		1 m conv 27 m long

Inco Ltd. Ontario Division	Levack				1 truck	90 m	490, 790 & 1100 m	305 m 910 m	diesel, trolley, & battery	
Inco Ltd. Ontario Division	Little Stobie						370 m 430 m	460 m 370 m	trolley diesel	1 m conv 1420 m long
Inco Ltd. Ontario Division	Stobie						430 m 550 m 670 m 730 m	460 m	trolley trolley trolley diesel	6 1.2m conv 76-310m long 1.5m conv 25 m long 1.2m conv 1430m long 1.2m conv 370 m long
LAC Minerals Ltd.	Macassa	Drift,Cross cut - 1.5t battery loco, 2t rocker cars & 4t						150 m	battery	
Minnova Inc.	Winston Lake	Ramp - loco & cars			2 13t trucks	460 m				
Noranda Minerals Inc. Geco Div.	Geco	Drift,Ramp - Granby cars, trucks		1.2 m belt, 760 m	13t trucks	46 m	200,690, 1050, & 1170 m	510 m	electric, & diesel	0.9m conv 480m long
Noranda Minerals Inc., Lyon Lake Div	Lyon Lake	Drift,Ramp - 13t truck		0.9 m belt, 270 m	4 trucks		550 m	700 m		
Placer Dome Inc.	Campbell	Drift - 40 cu.ft. cars 90 cu.ft. side dump cars						150-610 m		gravity conveyor
Placer Dome Inc.	Detour Lake				2 26t trucks					gravity
Placer Dome Inc.	Dome	Drift - 5.5t battery loco with Granby 85 cu.ft. cars					various 490 m	610 m 1160 m	trolley trolley	1.2 m conv 30 m long
Rio Algom Ltd.	Quirke	Drift - trucks, 6t battery locos, 8t trolleys Granby 7t cars		0.9m belt, 710 m 1.4m belt, 1100 m	3 26t trucks 2 13t trucks	to 610 m		3050 m max	trolley, diesel, & battery	0.9m conv 710 m long
Rio Algom Ltd.	Stanleigh	Drift,Ramp - 12t trolley, 250 cu.ft. cars					1130 m	1680 m	battery, & trolley	1 m conv 60 m long
Teck-Corona Operating Corp	David Bell							914 m		gravity
Westrock Industries Ltd	Drumbo		120 m	0.8 m belt, 914 m		240 m				0.8m conv 30 m long
Williams Operating Corp	Williams	Drift,Ramp - truck		1.524 m belt, 100 m long	22 trucks	300 m				1.5m conv 100 m long 1.0m conv 650 m long

Open Pit Mines in Ontario

Company	Mine	Location	Minerals	daily tonnage	transport & distance to crusher	transport & distance to mill from crusher
Indusmin Ltd	Badgely Island	Killarney	high grade silica	4000	35t trucks, 1100m	
Placer Dome Inc	Dome	South Porcupine	Au, Ag	820	trucks, 60 m	0.8m conveyor, 305 m
Williams Operating Corp		Hemlo	Au	100	4 trucks, 700 m	1.066m conveyor, 450m